PAPER NO. 84-2603

CO-GENERATION USING WIND AND DIESEL FOR IRRIGATION PUMPING

by

R. Nolan Clark
Agricultural Engineer
Wind Powered Irrigation Research Unit
USDA-Agricultural Research Service
Bushland, Texas 79012

For presentation at the 1984 Winter Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Hyatt Regency, New Orleans, Louisiana
December 11-14, 1984

SUMMARY:
The wind-diesel system used both a diesel engine and a wind turbine operating together to power an irrigation pump. The combination system was used because wind power alone does not always provide sufficient water at critical stress periods. The wind turbine reduced the load on the engine by 80% but fuel consumption was not reduced below 50%.

American Society of Agricultural Engineers
St. Joseph, Michigan 49085

CO-GENERATION USING WIND AND DIESEL FOR IRRIGATION PUMPING[1/]

R. Nolan Clark[2/]

ABSTRACT

Irrigation systems must be capable of supplying the needed amount of water at the critical plant water stress periods, which occur in mid-summer for most crops. Wind power alone normally has difficulty in supplying all of the energy needed for irrigation during these peak water-use periods. However, with a wind-diesel pumping system as described in this paper, sufficient water is supplied and diesel fuel is saved. The wind-diesel system uses both a diesel engine and wind turbine operating together to provide power to the pump. When the windspeed is 6 m/s or greater, wind power reduces the load on the diesel engine and fuel is saved. The vertical-axis wind turbine, rated at 40 kW, reduced the load on the engine from 47 to 9 kW and reduced fuel consumption by 50% in windspeeds above 16 m/s. Using an irrigation season of March through October and pumping 2000 h, seasonal fuel savings were predicted to be 13%. Greater savings would have been achieved if the wind turbine had been larger to better match the pumping load.

INTRODUCTION

Irrigation pumping requires large amounts of power because crops like corn, rice, cotton, and wheat transpire 1.2 cm of water per day, thus requiring a flow of 1.0 L/s per hectare. This flow represents the amount of water that must continuously be available to meet the evaporation demands and not limit crop growth. Irrigators prefer to have between 30 and 50 L/s available from their pumps. Power requirements then range between 10 and 150 kW, depending on lift and discharge pressure. Electricity, natural gas, and diesel fuel are the major forms of energy presently used to power the approximately 500,000 on-farm irrigation pumps in the United States. Diesel fuel is used to power many of the larger pumps and provides about 10% of the energy used in irrigation. On farms where irrigation is practiced, irrigation pumping energy accounts for 40 to 70% of the energy used.

Wind-powered irrigation systems have been developed by the USDA-Agricultural Research Service, Bushland, Texas, to supply at least 20 L/s to irrigated crops. These systems include ones that incorporate conventional power sources with wind power, called

---

1/ Contribution from USDA, Agricultural Research Service, Bushland, TX; in cooperation with The Alternative Energy Institute, West Texas State University, Canyon, TX.

2/ Agricultural Engineer, USDA-ARS, Conservation and Production Research Laboratory, Bushland, TX 79012.

wind-assist, and autonomous wind-powered pumps. Some systems produce electricity, while others are solely mechanical. In this paper, results from the wind-assist systems which combine wind and diesel will be presented.

The wind-assist pumping concept has several advantages over a wind-alone concept: 1) water can be pumped and distributed to the crops during critical water-use periods regardless of windspeed, 2) a constant pump speed is maintained for good pump efficiency and optimum well yields, 3) the system is easily adapted to existing irrigation pump installations without exchanging pumps or other existing equipment, and 4) a consistent water flow permits efficient application of irrigation water and good water management. A shortcoming of the wind-assist pumping concept is that it requires the use of a conventional power source.

DESCRIPTION OF TEST SYSTEM

The wind-diesel is a mechanical wind-assist pumping system that uses both a vertical-axis wind turbine and a diesel engine to power a deep-well irrigation pump. The diesel engine was sized to operate the pump on a stand-alone basis and ran continuously when irrigating. The wind turbine was coupled to the pump shaft through an overrunning clutch and combination gear drive and furnished power only when the windspeed exceeded 6 m/s (Fig. 1). The wind turbine thus reduced the load on the diesel engine rather than replacing the engine.

Wind Turbine

The wind system consisted of a vertical-axis wind turbine rated at 40 kW in a 15 m/s wind; however, the maximum power achieved was 35.9 kW at 16 m/s. Wind turbines are usually rated at their peak power. It was erected on a 9.1-m stand-alone tower and was supported at the top by four steel cables. The rotor was 16.7 m high and had an equatorial diameter of 11.5 m.

The turbine rotated at 81 r/min and utilized a speed increasing gearbox and timing belt to raise the shaft speed to 1780 r/min when the windspeed was above 6 m/s. The high-speed shaft was connected to the pump gear drive with an overrunning clutch which synchronized the shaft speeds of the wind turbine and the diesel engine (Clark and Schneider, 1980). The clutch allowed power to be transmitted to pump without power being transferred back to the wind turbine in low windspeeds.

A small electric motor was used to accelerate the rotor to insure starting each time. To stop the rotor, a 75-cm diameter disk brake with three double-action calipers was used.

Pumping System

The entire pumping system was assembled using commercially available equipment although the wind turbine was specially ordered. A vertical-turbine pump which was installed in the well several years earlier was used without modification. The pump delivered 19 L/s against a total dynamic head of 100 m. Water was pumped into an underground pipeline and used to irrigate wheat, soybeans, and grain sorghum from March through October.

The diesel engine was rated at 57 kW continous duty and was of the type normally used on generators or other industrial applications. The normal operating speed of the engine was 1750 r/min, the same as the pump.

A dual drive gearhead (Fig. 1) allowed power to be transmitted to the pump from either the diesel engine or the wind turbine or both simultaneously. The rotational speed of the entire system was controlled by the engine governor.

Data System

The data acquisition system consisted of a remote data station at the irrigation well and an automatic base station in a nearby laboratory. Output from all data sensors was routed to the remote data station where continuous data were available to be sampled by a minicomputer. The base station averaged rapid data inputs and computed statistical parameters at user controlled intervals. All data were sampled at a rate of 4.5 times per second and usually averaged over a 15-second interval. The averages and standard deviations were stored on a floppy disk and later transferred to a mainframe computer for processing (Clark et al., 1981).

Cup anemometers were installed on a nearby meteorological tower at 10-, 20-, and 30-m heights which were approximately the bottom, center, and top of the wind turbine rotor, respectively. Wind direction, air temperature, and atmospheric pressure were also measured to characterize the wind resource.

Torque transducers and shaft speed counters were installed in both the wind turbine and diesel engine drive lines. These transducers provided independent measurements of the power consumed by the pump. The volume of fuel flowing to the engine was measured by a precision flow transducer. A propeller meter was used to measure the water flow and two pressure transducers were used to determine the pumping lift and discharge pressure.

Data were collected during two irrigation seasons and in each of the months, March through October. Table 1 contains a summary of the important parameters measured and indicates the range of windspeeds where data were collected.

RESULTS AND DISCUSSION

The operating performance of each component of the wind-diesel pumping system is shown in Fig. 2. The turbine power and diesel power were measured by torque transducers in each drive line. The pump power was determined by combining the two measured powers and checked by water power calculations. Pump power remained almost constant at 46 kW during all pumping test. The power provided by the wind turbine followed the typical power curve for a vertical-axis wind turbine operating at a constant speed. No power was provided from the wind turbine until the windspeed exceeded 6 m/s and increased uniformly until it peaked at 35 kW in a 16 m/s windspeed. Diesel power was reduced from a maximun of 47 kW for low windspeeds to 9 kW for windspeeds above 16 m/s.

In low windspeeds when the diesel engine was supplying all of the pumping power, it consumed 3.8 ml/s of fuel (Fig. 3). The engine's fuel consumption was calculated to be 0.286 L/kWh which compares to a fuel consumption of 0.273 L/kWh for a well maintained, efficient engine (Schneider, 1983). Fuel consumption decreased with reduction in load to 1.9 ml/s when the diesel engine was producing 9 kW of power and windspeed was above 16 m/s. The reduction in fuel consumption as load is reduced is shown in Fig. 4. The reduction is linear between 100 and 20% of load but fuel consumption never dropped below 50%. Also shown in Fig. 4 are the windspeeds at which these reductions in loads occurred. Little fuel is saved until the windspeed exceeds 9 m/s, which is above the average windspeed of 6 m/s during the pumping season.

Using 17 years of windspeed data from the Amarillo NWS station, monthly energy production from the wind turbine and the volume of fuel saved was determined. The annual energy available from the wind turbine was 61,076 kWh or only 65% of the energy needed to operate the pump 2000 hours, the average pumping time per year in the Southern Plains. Assuming that the pump would operate at times of crop water needs regardless of the windspeed and that the windspeed during pumping would have the same distribution as the monthly ones, the fuel savings was calculated at 13%.

The poor performance of the wind-diesel system may have been caused by two conditions. First, the wind turbine was not large enough to sufficiently unload the diesel engine. A substantial amount of fuel was not saved until more than 30% of the load was removed from the engine. Second, the wind turbine used in this experiment was designed and built in 1978 and significant improvements in efficiency have been made since that time. Fig. 5 compares the efficiency of this wind turbine with a newer design that is more streamlined and is of the current design (Clark, 1984). The new unit has an efficiency of almost twice that of the one used in this study. Also, the newer design begins producing substantial power at a lower windspeed, thus better matching the predominate winds during the irrigation season.

CONCLUSIONS

The wind-diesel system was easily assembled from commerically available equipment, except for the mechanical wind turbine which was specially ordered for an earlier study. The dual-drive gearhead, engine, drive shafts, and clutch were all available at local irrigation equipment suppliers. An old pump was used without modification. All components were operated for two irrigation seasons with minor adjustments at the beginning of each irrigation season. No major operational problems were encountered.

The wind turbine did successfully unload the diesel engine and reduce fuel consumption. However, the wind turbine was not large enough to significantly unload the engine except in high winds. In order to provide a significant fuel savings, the wind turbine needed to carry at least 30% of engine load in a 7 m/s wind instead of 9%. The data presented here also show the need for good load matching when two independent energy sources are used in a single application.

Even though the system performed well and all components responded as expected, the results were discouraging because little fuel was saved. There appears to be little application for a system that saves only 13% and requires an initial investment of approximately $50,000. By using a newer designed wind turbine that is twice as efficient and providing a better load match, the fuel savings might be improved enough to make a system profitable.

REFERENCES

1. Clark, R. N. 1984. Electrical generation using a vertical-axis wind turbine. Transactions of ASAE 27(2):577-580.

2. Clark, R. N. and A. D. Schneider. 1980. Irrigation pumping with wind energy. Transactions of ASAE 23(4):850-853.

3. Clark, R. N., A. D. Schneider, V. Nelson, E. Gilmore, and R. E. Barieau. 1981. Wind energy for irrigation--wind-assisted pumping from wells. Final Report DOE/SEA731520741/81/3. National Technical Information Center.

4. Schneider, A. D. 1983. Selection of efficient irrigation pumping equipment. Proc. of the West Texas Irrigation Conf., Ft. Stockton, TX, Jan. 25, 1983.

TABLE I. Performance data collected for the wind-diesel pumping system.

Wind-speed	No. of obs.	Diesel power	Turbine power	Fuel flow	Power co-efficient	Dynamic head	Water flow
m/s		kW	kW	ml/s		m	L/s
5.0	47	47.6	0.0	3.78	.05	102.6	19.2
5.5	108	46.7	0.1	3.77	.05	103.0	19.2
6.0	171	46.5	0.2	3.77	.05	103.2	19.1
6.5	297	44.8	1.2	3.69	.07	103.5	19.1
7.0	387	42.9	2.8	3.59	.13	103.8	19.1
7.5	397	40.9	4.6	3.49	.17	104.0	19.0
8.0	451	38.4	6.6	3.37	.20	104.4	18.8
8.5	465	35.5	8.9	3.23	.22	104.9	18.7
9.0	492	32.8	11.2	3.09	.23	105.2	18.6
9.5	486	30.4	13.3	2.98	.24	105.4	18.7
10.0	468	27.5	15.8	2.83	.24	105.8	18.6
10.5	436	24.7	18.4	2.70	.24	106.2	18.8
11.0	372	23.1	20.0	2.63	.23	106.3	19.1
11.5	328	20.5	22.5	2.51	.22	106.8	19.3
12.0	270	18.3	25.1	2.41	.22	107.2	20.0
12.5	259	16.6	26.9	2.32	.20	107.4	20.3
13.0	298	14.0	29.3	2.21	.20	107.9	20.4
13.5	337	12.9	30.7	2.14	.18	107.9	20.7
14.0	338	12.0	31.7	2.11	.17	108.1	20.8
14.5	351	10.6	32.9	2.04	.16	108.4	20.8
15.0	311	9.7	33.8	1.99	.15	108.5	20.7
15.5	258	9.1	34.4	1.97	.14	108.5	20.8
16.0	252	8.8	35.1	1.94	.13	108.4	21.1
16.5	188	8.0	35.9	1.91	.12	108.6	21.0
17.0	148	8.4	35.7	1.91	.11	108.4	21.1
17.5	126	8.7	35.7	1.92	.10	108.3	21.2
18.0	74	9.4	35.2	1.93	.09	108.0	21.2

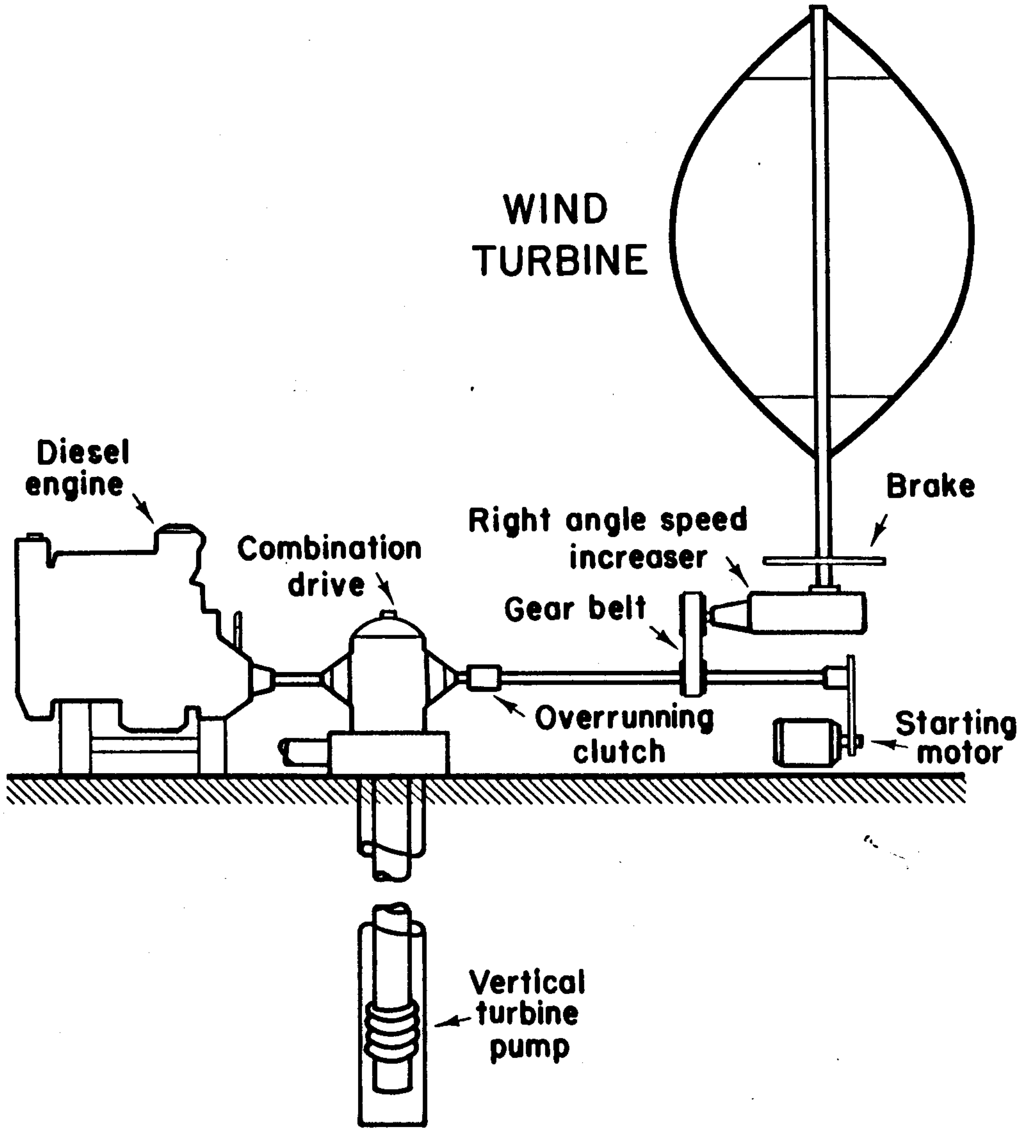

Fig. 1. Schematic of a mechanical drive wind-diesel irrigation pumping system.

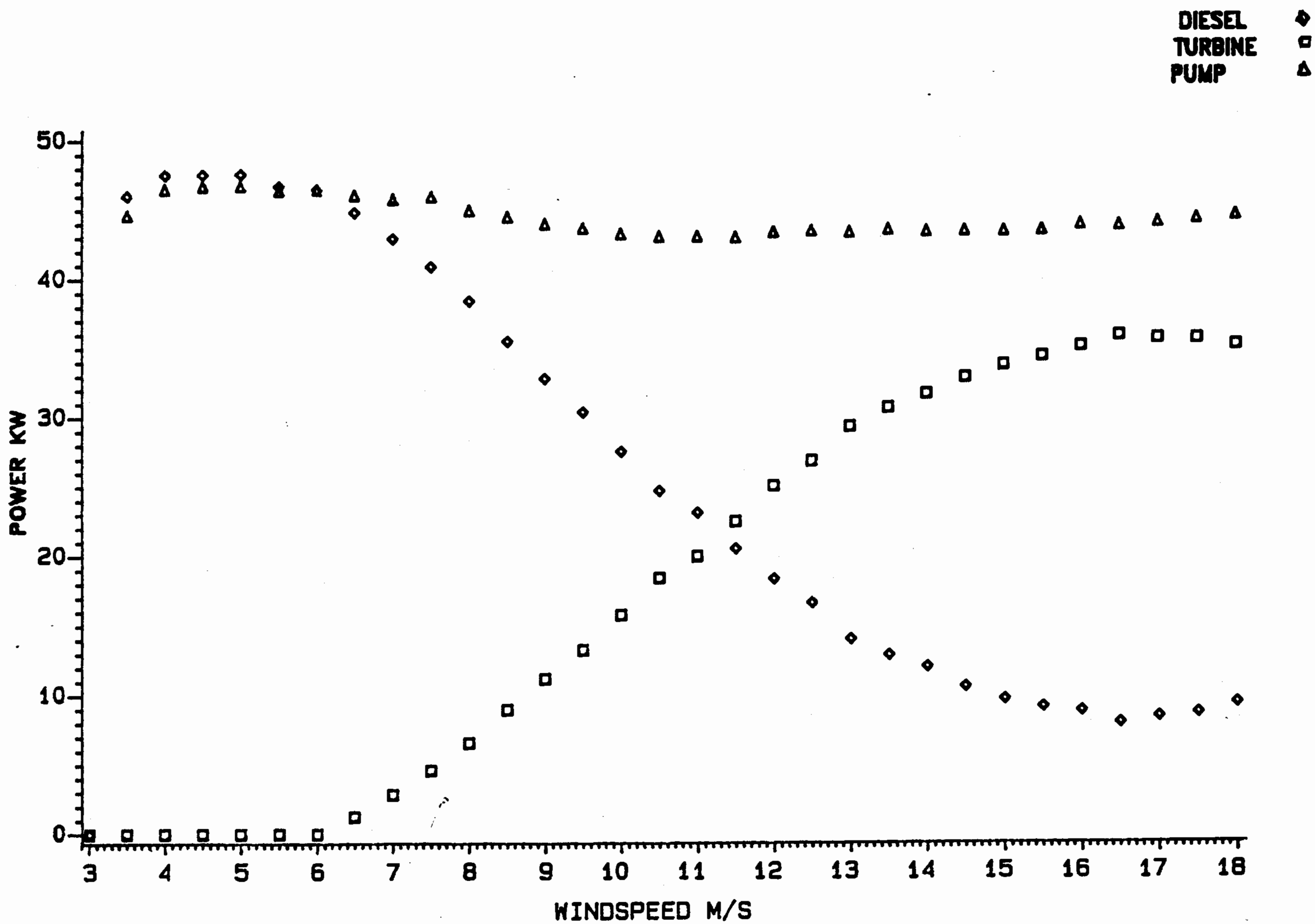

Fig. 2. Power output of the diesel engine and wind turbine and power consumed by the pump as a function of windspeed.

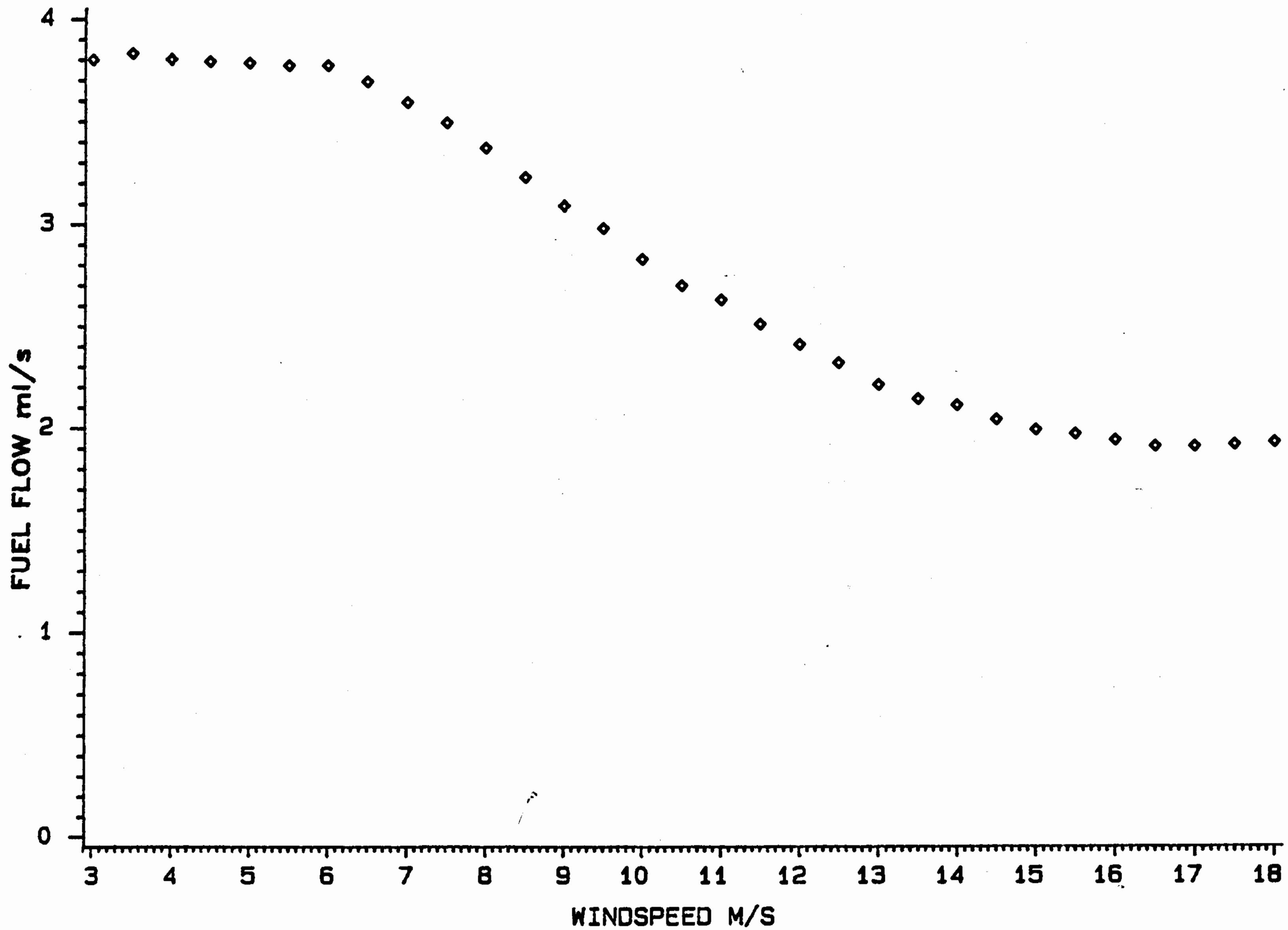

Fig. 3. The rate of diesel fuel consumed by the diesel engine as a function of windspeed.

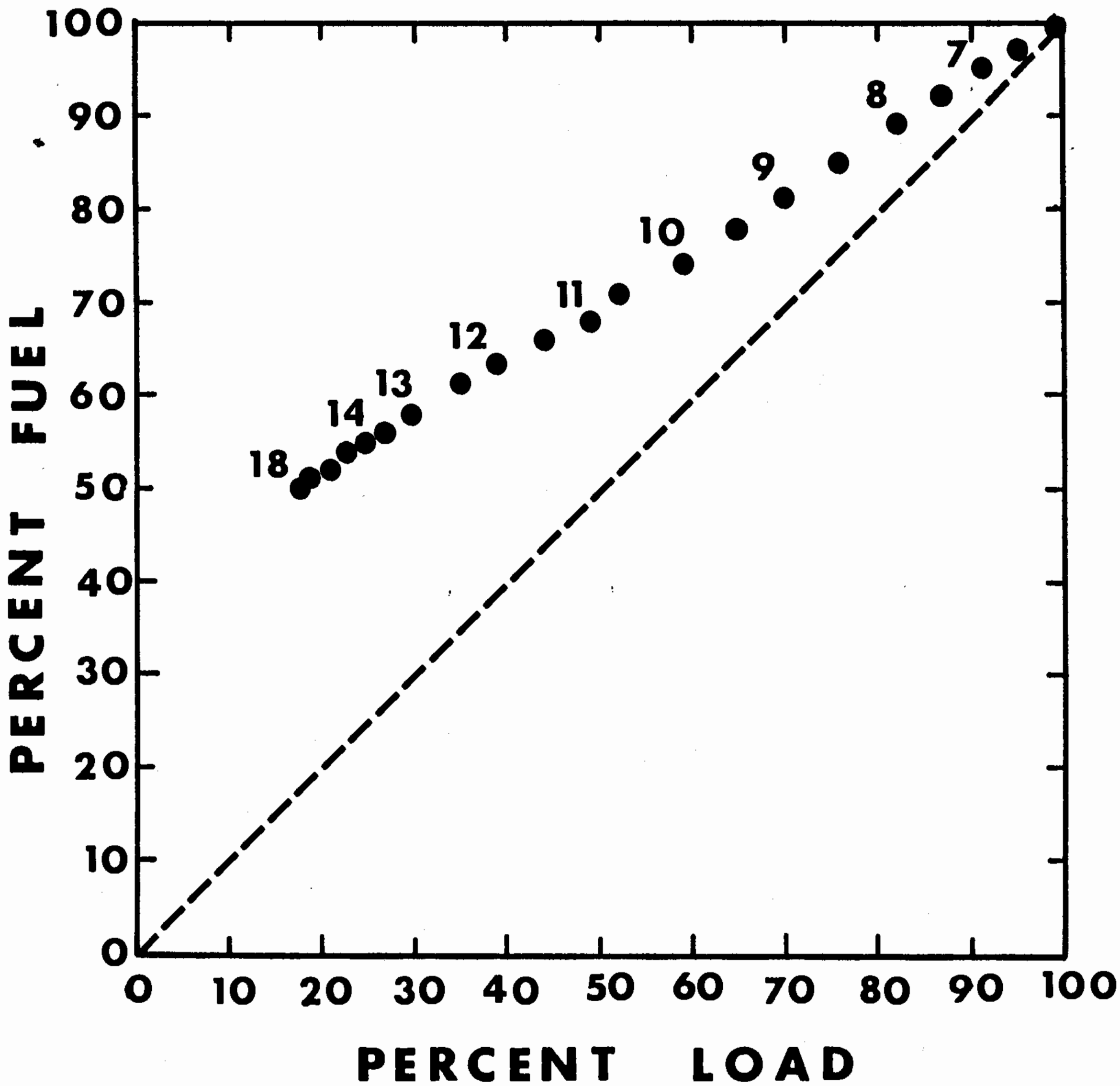

Fig. 4. The reduction in fuel consumption when the diesel engine is operated at reduced loads. Numbers indicate the windspeed at which the reduction was determined.

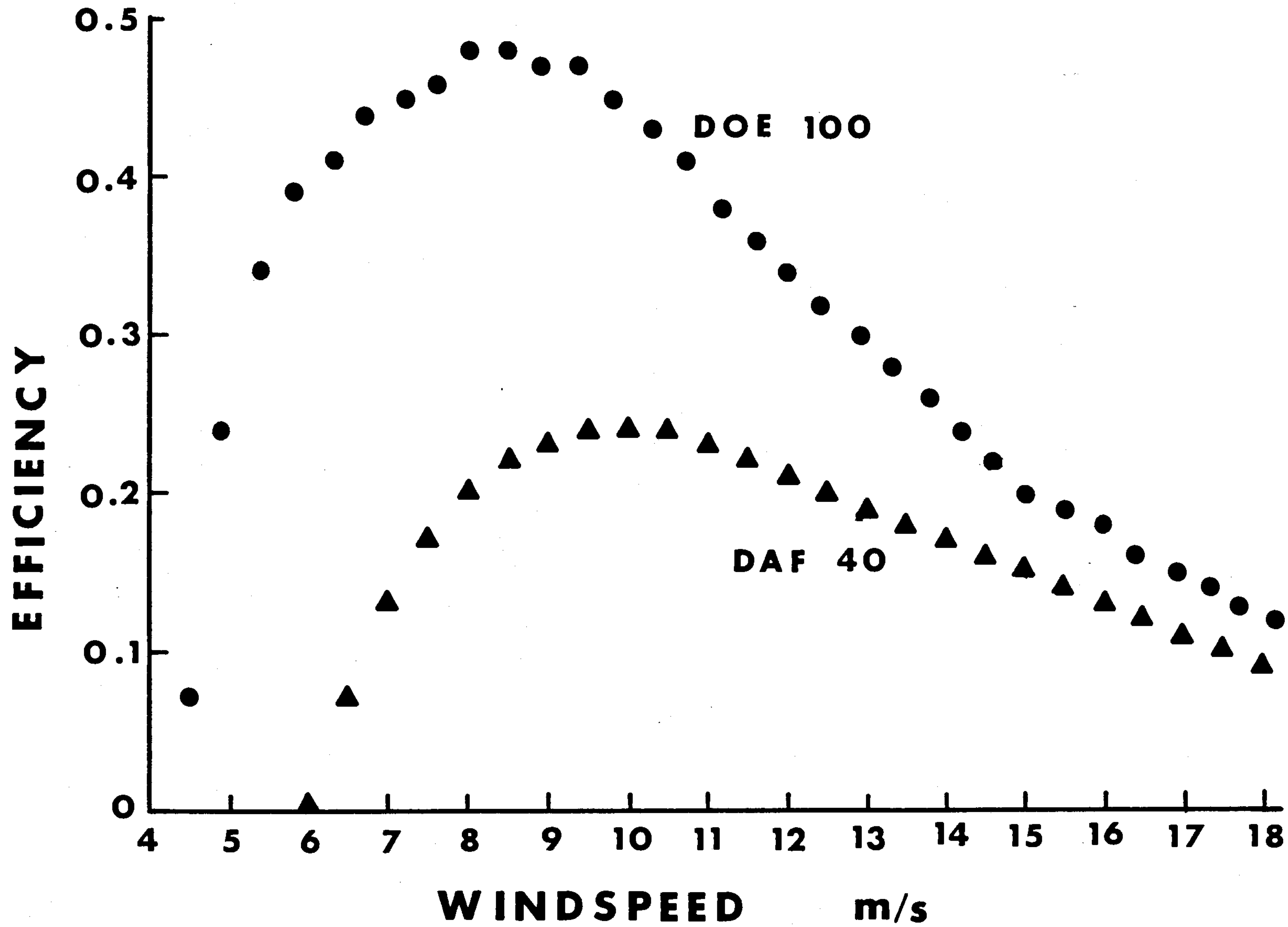

Fig. 5. Comparison of the efficiency of the wind turbine used with the diesel engine (DAF 40), 1978, and a newer design (DOE 100), 1981.